What factors of early-stage innovative projects are likely to drive projects' success? A longitudinal analysis of Korean entrepreneurial firms

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Abstract

Previous studies have identified the factors affecting successful technology commercialization as outcomes of R&D projects. However, most of them have used cross-sectional data, whereas there is a dearth of literature using longitudinal data analysis. Longitudinal analysis is essential for investigating the characteristics of early-stage innovative projects due to the inherent time lag between project evaluation and commercialization. Therefore, this study examines the early-stage project characteristics that can be used as meaningful evaluation criteria for predicting success, particularly in technology commercialization. We collected data on the *ex-ante* evaluation results and *ex-post* commercialization results of R&D projects pursued by entrepreneurial firms. We then conducted a logistic regression analysis and identified three market-related factors as significant in driving technology commercialization success in the early stages of technology development: market potential, commercialization plan, and market condition.

Keywords**:** Technology commercialization, technology evaluation, early-stage innovative project, commercialization success, SME, Korea

Keywords**:** L26 – Entrepreneurship, O32 – Management of Technological Innovation and R&D

1. Introduction

Studies have investigated the factors affecting successful technology commercialization from various perspectives (e.g., Bandarian, 2007; Kang et al., 2013; Rahal and Rabelo, 2006), as summarized by Kirchberger and Pohl (2016). These factors have been used as criteria for evaluating early-stage R&D projects (called "innovative projects" in this study) in terms of their commercialization potential (e.g., Altuntas and Dereli, 2012; Chen et al., 2011). Despite their value, however, previous studies have several limitations. First, most of them have used cross-sectional data surveys to investigate the characteristics of the technologies and external environments affecting technology commercialization success (e.g., Cheng and Li, 2005; Davoudpour et al., 2012), which may cause several problems. A longitudinal analysis is essential for this type of study due to the inherent time lag between technology evaluation and commercialization. Moreover, evaluations of the project and of the success of its technology commercialization can be separated in a longitudinal analysis, enabling the elimination of retrospective bias. Second, few studies have considered diversity when defining the success of technology commercialization. Different studies present different concepts of commercialization stages and success (e.g., Chen et al., 2011; Jolly, 1997). A comprehensive understanding is needed in order to analyze the factors affecting successful technology commercialization. This study aims to provide such an understanding.

To address the above-mentioned limitations, this study aims to address the issue of how the initial characteristics of an R&D project contribute to determine its future market (commercialization) success. We begin by conducting a comprehensive literature review on the success of technology commercialization and the success factors of innovative projects. Next, we collect data on the *ex-ante* evaluation of early-stage technologies and their *ex-post* commercialization success. Using the two sets of data, we conduct a logistic regression analysis and identify the determinants influencing the success of technology commercialization at the early stages of technology development. This study contributes to the entrepreneurial literature by investigating the factors affecting technology development and commercialization performance, and thus shaping project-management strategies. These research findings are expected to be helpful for entrepreneurial firms in their strategic technology planning, for venture capitalists in their investment strategy, and for policymakers in their development of effective programs for supporting small and medium-sized enterprises (SMEs).

The remainder of this paper is organized as follows. Section 2 reviews studies concerning the success of technology commercialization and provides the theoretical background of this study. In section 3, the study's research design and methods of application are explained. Section 4 presents the analysis results and insights gained from them. The relevant issues identified from the analysis are discussed in Section 5. Finally, the contributions, implications, and limitations of this study are addressed in Section 6.

2. Literature review

2.1. Definition of technology commercialization success

Technology commercialization denotes, in general, the application of a technology in product and service offerings to produce benefits. The commercialization process consists of various stages, as summarized in Table 1, and success differs at each stage. These differences in the stages of technology commercialization make it difficult to define technology commercialization success. As performance fluctuates, technology evaluated as successful at one point may turn out to be unsuccessful at another point. These difficulties in evaluating commercialization success have been encountered for decades. They were mentioned by Jolly (1997), who argued that the success of a current stage could not guarantee the success of the following stages because uncertainty was evenly distributed within the technology commercialization process.

--- Table 1 ---

A macro-level evaluation of technology performance in a market might produce more accurate results than other types of evaluation. In this case, however, data collection can be difficult given the focus on early-stage technologies, which require a relatively long period of development to arrive at the final commercialization stage. Therefore, the willingness (or expectation) to continue to (or arrive at) the next stage of technology commercialization was used at a proxy for successful technology commercialization if the technologies to be evaluated had not yet reached their final stage. According to Vroom (1964), expectations of success among entrepreneurs positively influence their willingness to devote their efforts to the project's success, which in turn, likely increases the potential for success. The willingness to move to the next stage indicates positive expectations for the performance of the SME's technologies. Only when they stop investing in the technologies are those technologies regarded as unsuccessful commercialization efforts.

2.2. Initial conditions for SMEs' innovative project success

As the needs for innovation have increased dramatically, significant efforts have been made to understand the process of identifying and deploying new technological opportunities in SMEs (Cho et al., 2016). As few studies have examined the initial conditions influencing the outcomes of SMEs' innovative projects, the literature review focused on the key success factors for technology commercialization at the early stages of R&D. The review results indicate that the success factors have been examined mainly from three perspectives: 1) technology-based, 2) organization-based, and 3) opportunity-based.

The first perspective focuses on the *technological characteristics* of an innovative project on the premise that its success comes mostly from commercializing excellent technology (Bruton and Rubanik, 2002). Fleming (2001) divided the technology innovation process into two stages—technological invention and commercial application—and argued that technological evolution can be significantly explained by purely technological sources of uncertainty. Follow-up studies such as Arts and Veugelers (2014) and Verhoeven et al. (2016) found empirically that patent indices representing the characteristics of technological invention had the potential to predict its future contribution to technological progress; that is, despite the inherent uncertainty of technological innovation, information on technological invention is enough to forecast its success. Indeed, technologies distinguished by their originality and impact are more likely to obtain internal and external support. If those technologies are at the growth stage, the chances of accessing internal and external funding may also increase. Furthermore, project teams developing such technologies are likely to be highly motivated and committed. According to Hoegl et al. (2004), project commitment has a positive relationship with teamwork quality, which means that a project with more commitment will be more likely to produce high-quality output. We expect that all these characteristics can positively influence R&D success from a technology development point of view. On the other hand, from a technology diffusion point of view, a product (service) will be adopted more quickly by potential users if it is more reliable, innovative, and compatible with existing products (services), which facilitates technology commercialization (Schilling, 2013).

Accordingly, for those taking this perspective, success factors may include the technological characteristics representing the quality of technological ideas or the nature of the technology itself; the characteristics of adoptability, innovativeness, originality, compatibility, simplicity, and reliability can be included in this category (e.g., Chen et al., 2011; Cho and Lee, 2013). Thus, we formulate the first hypothesis (H1) as follows:

H1. The technological characteristics of an innovative project affect its future commercialization performance.

From the second perspective, the success of innovative projects is driven by *organizational capabilities*—specifically, the ability to capture value from the innovation (Kostopoulos et al., 2016; Park and Ryu, 2015). These capabilities represent the efficiency or effectiveness of an organization in successfully developing its target technology and in utilizing the technology; they are related to the identification and acquisition of available internal and external resources to make their innovative projects successful (e.g., Kim et al., 2011; Liao et al., 2015). Such capabilities are particularly significant in SMEs' projects, as SMEs are likely to suffer from a lack of resources (Lee et al., 2010), which may prevent these projects from successful completion. Moreover, it should be noted that various capabilities concerning R&D, manufacturing, and marketing are essential for early-stage R&D projects to reach successful commercialization, whether they be internally developed or externally acquired. Considering SMEs' limited internal capabilities, having a wide and strong network of relationships that enables the firms to identify, acquire, and deploy external resources for technology development and commercialization is as important as having internal R&D capabilities. In SMEs, these networking contacts are likely to be related with the competitiveness of managers.

Therefore, we consider such organizational capabilities as determinants of the future commercialization performance of an innovative project, where both R&D capabilities (to build internal resources) and managers' competitiveness (to access external resources) are taken into account. Thus, the second hypothesis (H2) is proposed as follows:

H2. The organizational capabilities for an innovative project affect its future commercialization performance.

The final category of studies has regarded innovative project success as the result of taking advantage of business opportunities (Dutra et al., 2014; Jeng and Huang, 2015), where *opportunity characteristics* are considered the determinants of success. Roztocki and Wistroffer (2016, p. 545) defined "business opportunity" as "the prospect to do business, determined by a ready market and supportive environment." Thus, success factors from this perspective are related to expected market demand, the attractiveness of target users, entry barriers, and the market competition level (e.g., Cho and Lee, 2013; Jeng and Huang, 2015), which represent market conditions as being the key opportunity.

On the other hand, a prospective idea with potential value for the customer or society becomes feasible and profitable only when exploited by entrepreneurial firms (Gaglio and Katz, 2001). The idea behind the innovative project needs to be translated into a form demonstrating its economic potential to make the project successful, as studies have shown by emphasizing the importance of technology commercialization (Timmons, 1999). Therefore, the opportunities' characteristics need to include the feasibility of the commercialization plan and expected economic impacts (e.g., Fink and Kraus, 2009), which indicate the firm's efforts and plans to seize the opportunity.

For these reasons, we assume that the opportunistic characteristics of an innovative project affect its successful commercialization, where such opportunities are associated with market conditions and organizational plans for the opportunities; they include both the opportunity itself, reflecting the conditions of the target markets for the technology, and the activities related to the search, recognition, and seizure of opportunities. Accordingly, the following hypothesis (H3) is developed:

H3. The opportunity characteristics of an innovative project affect its future commercialization performance.

3. Research framework

3.1. Research design

We compared two datasets, one provided by the Korea Institute of Science and Technology Information (KISTI) program (i.e., *ex-ante* evaluation results) and the other created ourselves through a survey (i.e., *ex-post* commercialization status). The *ex-ante* evaluation results contain the evaluation results on projects using the 26 indices when the technology was at its early stages of development; the indices are based on a five-point Likert scale with different weights. The *ex-post* commercialization status describes the degree of project performance with respect to the current state of technological commercialization progress. An e-mail survey was conducted to collect the data.

The two datasets were linked, as shown in Figure 1, and the following analyses were conducted. First, an exploratory analysis was conducted to compare the differences in the index values between successful and unsuccessful cases. This comparative analysis was also performed when the cases were divided into different groups according to company size and commercialization stage to investigate whether the differences in the index values showed different patterns for firms of different sizes at different stages of commercialization. Second, an in-depth analysis was performed to investigate the relationships between the index values and commercialization results through a logistic regression analysis.

--- Figure 1 ---

3.2. Data collection

The first dataset of *ex-ante* evaluation results was acquired from KISTI, a government agency in Korea. From 2002 to 2013, 778 SMEs with novel technological ideas applied to the KISTI funding program. KISTI used its own evaluation model to examine the conditions of projects and provide feedback on them. As the evaluation model was consistent only after 2008, the available data for this study were limited to projects begun after that date. It should be noted that most of the SMEs involved in this evaluation process accessed the funding successfully (with a very few exceptions), and thus the effect by the funding on successful technology commercialization can be controlled. The KISTI model consists of 26 indices, as shown in Table 2 (see Appendix A for details). We were not involved in developing the indices but reviewed the references to validate their use in assessing the initial conditions of the R&D projects (see Table 2). This reappraisal not only made us confident that the KISTI model has a sound theoretical basis but also allowed us to check whether these indices were good enough to predict actual commercialization success.

--- Table 2 ---

To collect a second dataset of *ex-post* commercialization status, we designed a survey questionnaire consisting of three sections. The first asked about the current stage of the commercialization process, quantitative outcomes such as IPRs or economic benefits from each stage, and the willingness of the SMEs to pursue commercialization. In this section, we divided the technology commercialization process into three sub-processes and six stages. The *technology development* process consists of two stages—*initiating development* and *technology establishment*; the *product development* process has one stage—*deriving outcomes*; and *market competition* has three stages—*market entry*, *creating benefits*, and *passing break-even point*. The second section asked about the general characteristics of the firm, such as the number of employees, amount of sales, and amount of R&D investment. Finally, the third section gleaned personal information about the respondents.

The target respondents of our survey were the SME employees in charge of conducting the innovative projects they had applied to the KISTI program for. We faced several difficulties in collecting longitudinal data. First, some of the SMEs no longer existed due to mergers and acquisitions (M&A) or shutdowns; for the former, we traced them and sent our questionnaire to the new company; for the latter, we regarded them as a failure. Second, respondents could hide their failures and respond disingenuously to the survey. The fear that they might no longer be supported by the public program due to project failure needed to be mitigated through additional effort during the survey. Third, some individuals might not have remembered whether they had applied to the KISTI program due to changes in the technologies or in their management teams.

Therefore, additional efforts were made to increase the response rate and data reliability. First, the objective of this research was clearly stated in the survey questionnaire to eliminate the fear that any failure experience might have a negative impact on future applications to other public programs. Second, the survey was followed with telephone calls, and respondents were offered gifts to increase the response rate and quality. Third, detailed information about the projects for which they had applied to the KISTI program were provided via telephone as well as a survey to improve the recall of the respondents. Finally, to address potential management team changes, a survey was sent to the CEO, who would be more likely to know the history of the projects.

The survey was conducted from August 8, 2014, to October 6, 2014. The population included 291 SMEs that applied to the KISTI support program between 2008 and 2013. During the survey, e-mails to 77 of the SMEs were returned with "invalid address" errors. We then tried to locate these firms both through the Internet and by telephone. We found that 53 of them had reorganized via M&A, and 24 had shut down; the e-mail questionnaires were sent to the 53 firms that had reorganized. Consequently, 88 of the firms responded, resulting in a response rate of 35.96%, which is relatively high considering the nature of longitudinal data. To test the non-response bias, a t-test was conducted on the basic profiles of the firm (i.e., sales, age, and size), and a Kruskal–Wallis analysis was employed on the industry distribution between responding firms and non-responding firms. The analysis results showed no significant differences between the two groups at a significance level of 0.05, indicating that the data can be considered free of the non-response bias. Five industries were included in the final sample: mechanical (28.4%), electronics (13.6%), chemical (20.5%), bio (11.4%), and information & communications technology (26.1%). According to the distribution of the commercialization process by firm, a total of six stages were considered: initiating development (13.6%), technology conceptualization (33.0%), deriving outcomes (28.4%), market entry (13.6%), value creation (8.0%), and passing the break-even point (3.4%). Most of the projects were still in the early stages of the commercialization process when we made contact.

4. Analysis model and results

4.1. Exploratory analysis to investigate potential factors

An exploratory approach was adopted to check for differences in the project evaluation results between successful and unsuccessful cases of technology commercialization, with a focus on diverse commercialization stages and firm size. The projects were divided into three groups according to commercialization stage to observe the differences of index values between success and unsuccessful cases for each group. These projects were again split into two groups by firm size to observe such differences in each group.

First, the 88 projects were assigned to either the successful or unsuccessful group. Then, a non-parametric test was employed to analyze the differences in index values between the successful and unsuccessful cases because the data were not normally distributed according to the Kolmogorov–Smirnova and Shapiro–Wilk tests. The analysis results indicate that only four indices—"lifecycle position of technology," "holding IPRs," "potential market growth," and "validity of commercialization plan"—showed statistically significant differences at a significance level of 0.1 (see Appendix B).

Second, if we consider the commercialization stages at which an innovative project was reached, more indices were identified as being significant in distinguishing the two cases. The analysis results show that "lifecycle position of technology," "holding of IPRs," and "validity of commercialization plan" are significant in the technology development process, "lifecycle position of technology," "ease of production," "potential market growth," and "validity of commercialization plan" in the product development process, and "technological contribution to a product," "expected economic ripple effect," and "validity of commercialization plan" in the market competition process, all at a significance level of 0.1 (see Appendix C).

Finally, the projects were divided into two groups by firm size, using the average value of 29.125. Only one index ("validity of commercialization plan") was observed to have a significant difference for firms with fewer than 30 employees, whereas six factors—"size of R&D personnel," "commercialization capability of mangers," "expected economic ripple effect," "holding of IPRs," "potential market growth," and "validity of commercialization plan"—showed a statistically significant difference at a significance level of 0.1 for companies with 30 employees or more. Early-stage evaluation may show more predictable results for relatively large SMEs (see Appendix D).

4. 2. In-depth analysis to identify key factors

4.2.1. Variables

As the evaluation model had 26 correlated indices, principal component analysis (PCA) was employed to resolve the multicollinearity problem and reduce the indices' dimensions. A set of principal components (PCs) as a result of PCA were used as independent variables. Then, a logistic regression was used to test the causality between the *ex-ante* evaluation results and *ex-post* commercialization performance. The dependent variable of this study is designed to have a binary value obtained from the survey.[1] The exploratory analysis suggested that the prediction of successful technology commercialization may be affected by firm size as well as commercialization stage; these two variables were used as control variables.

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[1] We regarded the following outcomes as indicating success: 1) the project has reached the final commercialization stage (i.e., value creation [Stage 4]); 2) the technology reached one of the commercialization stages (i.e., technology conceptualization [Stage 1], deriving outcomes based on the technology concept [Stage 2], market entry [Stage 3], and the SMEs were willing to move on to the next stage. This operationalization allowed us to design a binary dependent variable, where 1 was assigned for success and 0 assigned otherwise.

4.2.2. PCA results

After conducting the oblique-rotated PCA, 10 PCs were identified as having an eigenvalue greater than 1 (see Table 3). The total cumulative variance of the 10 PCs is 68.78%; these represent about 69% of the variance in the original variables. PC1 is thought of as *technological utility*, as it has high-loading values for "degree of technological leading edge," "technological contribution to a product," "applicability and extendibility of technology," and "availability of alternative technology." The second PC is called *R&D competitiveness*. A project with a high PC2 score may be technology-intensive because it is closely related to "validity of technology development plan," "size of R&D personnel," "expertise of R&D employees," and "public certification records." PC3 is labeled *pioneer spirit in a new market*. A project with a high PC3 score is likely to enter a market with "a stable demand structure," even if the strategic compatibility of the technology is low. PC4 is called *market potential*. Projects with a high PC4 score may expect extensive future market growth because "potential market size" and "market growth" have high loading values. PC5 can be summarized as *managerial competitiveness* due to the high-loading values of "manager experience in similar fields," "commercialization capability of managers," and "career of managers." PC6 can be called *infeasible commercialization* plan, meaning that projects with low PC6 scores have relatively systematic plans due to the low-loading values of "strategic compatibility of commercialization" and "validity of commercialization plan." PC7 is defined as a *hazardous market condition* since the loading values for "degree of market competition," "barriers of market entry," and "expected market share" are all negative. A project's target market is under fierce market competition if the PC7 score is high. Only one index, *ease of production*, has a high loading value in PC8. PC9 can be called *expected positive economic impact* because it is focused on "the possibility of an alternative technology," "high expected return," and "high expected economic ripple effect." Finally, "holding IPRs" has a significantly negative effect on PC10, meaning that a project with a low PC10 score has made greater effort to acquire IPRs. Thus, PC10 can be defined as *lack of IPRs*.

--- Table 3 ---

4.2.3. Logistic regression analysis results

The results of the logistic regression are described in Table 4. Five PCs had a statistically significant impact on successful technology commercialization at a significance level of 0.05. First, the possibility of successful technology commercialization increases significantly when the projects have high *market potential (PC4)*. Second, an *infeasible commercialization plan (PC6)* has the greatest negative impact on the success of technology commercialization. Third, the *lack of IPRs (PC10)* had a negative effect on the success of technology commercialization. Fourth, particularly interesting was the negative effect of *ease of production (PC8)* on achieving successful technology commercialization, which is contrary to expectations. It could naturally be assumed that early-stage technology that is easier to produce would more readily achieve commercialization. Interestingly, SMEs were more willing to commercialize their technology when their target products or services were more difficult to produce, possibly because these difficulties could lead to higher barriers to market entry, making it difficult for new firms to enter a market. Finally, a strong *hazardous market condition (PC7)* decreases the possibility of successful technology commercialization. On the other hand, the other five PCs—*technological utility (PC1)*, *R&D competitiveness (PC2)*, *pioneer spirit in a new market (PC3)*, *managerial competitiveness (PC5), and expected positive economic impact* (PC9)—had no statistically significant effect on the success of technology commercialization. H1 and H2 were only partially supported, with H3 was fully supported.

--- Table 4 ---

5. Discussion

The analysis results offer several issues for discussion. First, the regression analysis shows that the only technology-related determinant is concerned with "ease of production." Technologies that are difficult to embody in products or services are more likely to be successful in commercialization. The ease of production has both pros and cons: it decreases the possibility of failure during production technology development and furthermore can boost up market dissemination of products or services (Tucker, 2012), whereas it may increase the degree of competition in a market by allowing competitors to enter it (Allen and Strathern, 2005). Here, the cons seem to outnumber the pros in the context of early innovative projects, as entrepreneurial firms are likely to be more wary of the threat of imitation (Lee et al., 2000) than of the risk of failure. Hence, firms need to acknowledge that a complex production technology has an advantage in that it can be a non-imitable resource despite the difficulties in acquiring it. In general, these findings are contrary to our expectation that technological features can predict commercial success, as is suggested by several studies (Fleming, 2000; Arts and Veugelers, 2014). This discrepancy may flow from 1) the differences in the unit of analysis or 2) the differences in the measurements used for technological characteristics. The unit of analysis in the previous studies is a technology, while it is a project in this study. In other words, the characteristics of a technology can explain its success but not the success of the project conducted to develop it.

The exploratory analysis produced interesting findings on the technology-related indices. First, the successful and unsuccessful cases (confined to projects at the market competition stage) showed statistically significant differences in “technological contribution to a product.” A greater contribution could mean greater changes in the products, which could increase the uncertainty in the technology and the market outcome. Such uncertainty may negatively affect technology commercialization success (Popadiuk and Choo, 2006). Accordingly, if a technology is of great importance for the product or services, continuous efforts to monitor and reduce such uncertainties are required. Second, the “lifecycle position of technology” also seems to be significant at the earlier stage of commercialization. Technology lifecycle has been regarded as a representative measure to make an investment decision (Haupt et al., 2007); if technologies are at the emerging or growing stages, firms tend to have a greater willingness to continue to commercialize their technologies with optimistic expectations.

“Lack of IPRs” is the only organization-related determinant that influences commercialization success significantly according to the regression analysis results. Firms that protect their early-stage technologies with IPRs are likely to be confident in their technologies; their potential for innovation is verified by the IPR system, and they are thus likely to continue to expend efforts in developing them (Chen, 2009; Jorde and Teece, 1990). IPR can be a meaningful proxy with which to predict the potential of the technology (Ernst, 2003). These findings are in line with Webster and Jensen (2011), who argued that the probability of commercialization decreases when a patent is not granted but increases when complementary patents are obtained. To entrepreneurial firms, IPRs can be a means of protecting their technologies as well as proof that their technologies are good enough to commercialize; thus, it is advantageous for firms to acquire IPRs where necessary.

Apart from the two above determinants (“ease of production” and “lack of IPRs”), the remaining determinants identified in the regression analysis include opportunity-related indices: “market potential” in terms of size and growth; “market condition” in terms of the degree of market competition, barriers to market entry, and expected market share; and “commercialization plan” regarding its strategic compatibility and validity. All of these need to be regarded as key criteria and must be carefully evaluated to identify promising early-stage innovative projects. Indeed, previous studies have addressed the importance of creating value by taking opportunities (Gaglio and Katz, 2001; Roztocki and Weistroffer, 2016); when an early-stage innovative project pursues such an opportunity, it is more likely to proceed to the commercialization stage. The exploratory analysis results also indicated that successful projects had more feasible commercialization plans than the others had regardless of their stage of technology commercialization. Such a well-developed plan can be an internal driver for proceeding in the commercialization process even when the project faces difficulties during the process, thereby highlighting the significance of project planning, which needs to be addressed effectively by entrepreneurial firms.

6. Conclusions

This study has investigated the factors that may affect the successful commercialization of early-stage innovative projects. We established a unique database consisting of two datasets: *ex-ante* evaluations results of innovative projects and *ex-post* commercialization results. Separating the source of the evaluation results from the source of the commercialization results allowed us to reduce the recall bias. We also took a longitudinal approach, thus increasing the reliability of the data collected. The research findings indicate that opportunity-related determinants have a greater impact on commercialization success than technology- or organization-related ones have. While most project evaluations have generally focused on organizational capabilities or technological characteristics, market opportunities seem to be the most significant factors for successful technology commercialization. To expand these findings, future research should 1) investigate the mechanisms by which such opportunity-related determinants affect the success of commercialization and 2) identify how entrepreneurial firms that can derive the most benefit from such opportunities. Moreover, additional external factors may affect the success of technology commercialization. For example, different R&D project results can be expected if they are affected by the difference between formal vs. informal manager networks, shifts in the dominant technological designs in a specific field, or different sets of resources. Not all of these factors can be controlled by focusing only on the initial conditions, but they need to be considered in future research.

Despite its meaningful contributions, however, this study has several limitations. First, though we made every effort to achieve a high response rate, the sample size was small due to the characteristics of longitudinal analysis. Second, this study defined technology commercialization success based on the willingness of SMEs to move to the next stage of commercialization. Other definitions may lead to other results. Finally, sample selection bias needs to be discussed. Although no significant non-response biases were observed, the study examined only a subset of Korean firms, which may cause a selection bias and hamper the findings' generalizability to all types of entrepreneurial firms in Korea.

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Figures

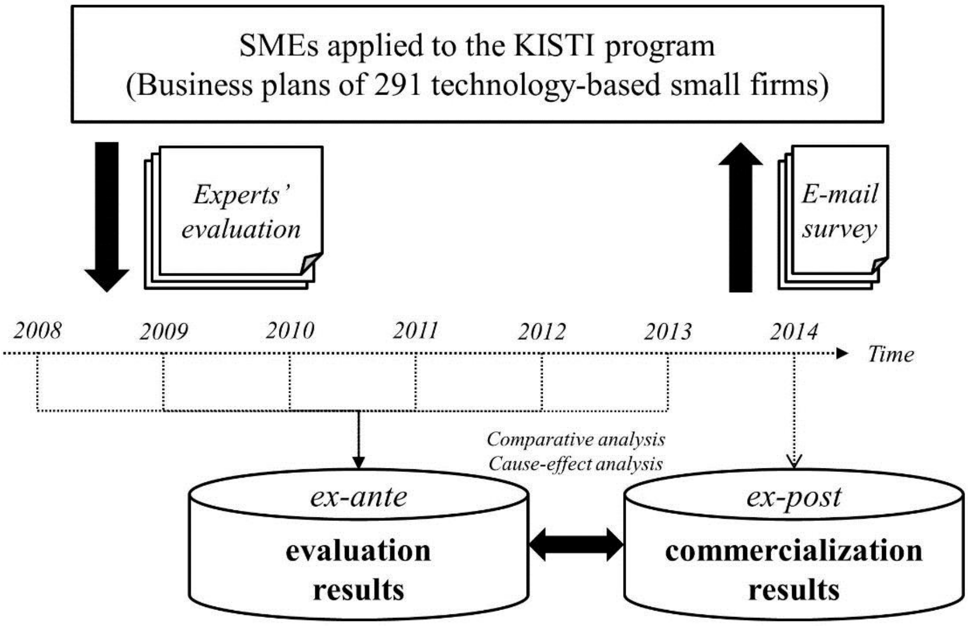

Figure 1. Relationship between the two datasets

Tables

Table 1. Technology commercialization process

Stage	Description	References
Technology conceptualization	Technology that is intended to be developed from innovative ideas is documented and its information is distributed or shared among members of the organization.	Jolly, 1997; Dhewanto and Sohal, 2015
Deriving outcomes based on the technology concept	Final outcomes (i.e., improved or new processes/products/services) are completely derived or developed based on established technology.	Cho and Lee, 2013; Dhewanto and Sohal, 2015
Market entry	Final outcomes of the technology enter a market in one form or another. - Improved or new products/services appear in the market. - Improved or new processes are applied to a facility or an organization.	Chen et al., 2011; Miller, 2007
Value creation	Profits are created over the break-even point or economic effects occur more than a certain level. - Sales of launched products/services that are based on the established technology recover overall pre-investments. - Significant cost reduction effects occur from applied processes. - Equity carve-outs through subsidiaries can be categorized into benefit creation.	Kim et al., 2011; Dhewanto and Sohal, 2015

Table 2. Indices of evaluation model

Category	Sub-category	Index	References
Technological characteristics	Innovativeness	Degree of technological leading edge (IN1)	Huang et al., 2008
		Technological differentiation (IN2)	Cho and Lee, 2013
		Lifecycle position of technology (IN3)	Park and Park, 2004; Chiu and Chen, 2007
	Technological competitiveness	Technological contribution to a product (TC1)	Park and Park, 2004
		Applicability and extendibility of technology (TC2)	Cho and Lee, 2013
		Ease of production (TC3)	Kim and Oh, 2010
		Availability of alternative technology (TC4)	Chan et al., 2000
	Strategic validity	Strategic compatibility of a technology (SV1)	Meade and Presley, 2002
		Validity of technology development plan (SV2)	Huang et al., 2008
Organizational capabilities	R&D Infrastructure	Size of R&D personnel (RD1)	Kim et al., 2011
		Expertise of R&D employees (RD2)	Mohanty et al., 2005; Cho and Lee, 2013
		Holding of IPRs (RD3)	Kim and Oh, 2010; Davoudpour et al., 2012
		Public certification records (Legitimacy) (RD4)	Goldberg et al., 2003
	Competitiveness of managers	Manager experience in similar fields (CM1)	Kumar and Jain, 2003; Mohanty et al., 2005
		Commercialization capability of managers (CM2)	Meade and Presley, 2002
		Career of managers (CM3)	Cheng and Li, 2005
Opportunity characteristics	Market attractiveness	Degree of market competition (MA1)	Meade and Presley, 2002; Cho and Lee, 2013
		Potential market size (MA2)	Chiu and Chen, 2007
		Potential market growth (MA3)	Kumar and Jain, 2003
		Stability of market demand (MA4)	Cho and Lee, 2013
		Barriers of market entry (MA5)	Cho and Lee, 2013
		Expected market share (MA6)	Mohanty et al., 2005; Chiu and Chen, 2007
	Economic effect	Expected return on investment (EE1)	Meade and Presley, 2002; Cheng and Li, 2005
		Expected economic ripple effect (EE2)	Cho and Lee, 2013
	Commercialization feasibility	Strategic compatibility of commercialization (CF1)	Davoudpour et al., 2012
		Validity of commercialization plan (CF2)	Kim and Oh, 2010

Table 3. PCA results

Index	Loading values of principal components									
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
IN1	.700									
TC1	.717									
TC2	.761									
TC4	.506								.537	
SV2		.549								
RD1		.700								
RD2		.693								
RD4		.618								
MA4			.728							
SV1			-.627							
MA2				.790						
MA3				.544						
CM1					.808					
CM2					.715					
CM3					.556					
CF1						-.806				
CF2						-.823				
MA1							-.558			
MA5							-.796			
MA6							-.764			
TC3								.878		
EE1									.601	
EE2									.699	
RD3										-.826
Percent variance of PC	9.782	8.761	7.712	7.186	6.582	6.288	5.735	5.705	5.650	5.379

* The loading values for two indices (IN2 and IN3) were less than 0.5 and were removed from this table.

Table 4. Logistic regression analysis results

Variables		Control variables (p-value: 0.031**)					Control and independent variables (p-value: 0.001**)				
		B	S.E.	Wals	p-value	Exp(B)	B	S.E.	Wals	p-value	Exp(B)
Control variables	Size of firm	-.595	1.366	.189	.663	.552	-1.362	2.186	.388	.533	.256
	Technology development				.037**				8.480	.014**	
	Product development	-2.177	1.082	4.051	.044**	.113	-4.559	1.711	7.098	.008**	.010
	Market competition	-.672	1.275	.278	.598	.511	-.036	1.610	.001	.982	.965
Independent variables	PC1						.404	.458	.781	.377	1.498
	PC2						-.459	.523	.772	.380	.632
	PC3						.100	.468	.046	.830	1.106
	PC4						.932	.512	3.320	.068*	2.541
	PC5						.226	.534	.179	.672	1.254
	PC6						-1.599	.794	4.062	.044**	.202
	PC7						-1.139	.551	4.280	.039**	.320
	PC8						-1.166	.542	4.625	.032**	.312
	PC9						-.190	.423	.202	.654	.827
	PC10						-1.582	.585	7.306	.007**	.206
	Constant	3.175	1.074	8.735	.003**	23.921	5.655	1.784	10.047	.002**	285.695
Model summary		**-2 Log likelihood**	**Cox & Snell R-square**	**Nagelkerke R-square**			**-2 Log likelihood**	**Cox & Snell R-square**	**Nagelkerke R-square**		
		71.462	.096	.161			46.415	.320	.535		